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SPRAY IRRIGATION OF DAIRY WASTES *

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The rural or semi-rural location of many small dairy plants, together with the high strength of their liquid waste, usually present a special problem in the disposal of such waste. Frequently the only drainage is a roadside ditch or a small stream, neither of which may be satisfactory for the removal of untreated or partially treated waste.

The cost of conventional aeration or trickling filter type treatment plants usually makes them impractical for the small dairy plant. Most investigators are of the opinion that irrigation provides a simple and economical method for disposal of these wastes wherever sufficient land with suitable topography and soil is available (1).

Dennis (2) noted that the first spray irrigation installation started operation in 1947 in Pennsylvania for disposal of cannery wastes, and that spray

irrigation of dairy wastes was initiated two years later in Tennessee. Schraufnagel (3) stated that there are now about 30 milk plants in Wisconsin using spray irrigation as a means of waste disposal. McKee (4) summarized the results obtained from the spray irrigation of dairy wastes at eight typical installations and concluded that the method has proven to be satisfactory. Kuhlman (5) favored the use of small holding tanks in order to maintain the wastes as fresh as possible. Breska *et al.* (6) reported on earlier phases of the studies reported herein. Other articles on spray irrigation of dairy wastes have appeared during the past few years (7) (8) (9) (10).

Procedure

The purpose of the study was to determine the effectiveness of spray irrigation as a method for the disposal of dairy plant wastes. The project included both the soils and the engineering aspects of the problem. The

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selections of the sites for the study were made with the cooperation of the Wisconsin Committee on Water Pollution. The soil and the availability of the sites were prime considerations in the selection, but for more details reference is made to Breska *et al.* (6). Six sites were selected, one of which was found later to be impractical, and the data obtained at another were extremely limited because of indefinite suspension of irrigation.

Early in the study routine information covering the milk intake, cheese production, depth of well, size and type of pump used, size of sump, type and quantity of irrigation equipment, and size of area being irrigated was obtained at each plant.

The daily volume of waste at each plant was determined by average drawdown rates in the sumps, coupled with duration of pumping. The duration of pumping was determined from clocks wired in parallel with the pump motor. At four of the plants water meters were installed at the well to check water usage.

Samples were obtained by the use of samplers developed during the project. Basically, these consisted of a splash plate offset over a funnel leading to a refrigerated sample bottle. A one-half inch line from the discharge side of the pump allowed a small stream of waste to fall on the

splash plate, which was so adjusted that during a 24-hr period an appropriate quantity of waste was diverted to the sample bottle.

The sanitary quality and chemical composition of the wastes were determined. Soil samples from irrigated and unirrigated areas at each site were taken with an auger to determine particle size distribution and chemical analysis, and with a core-type sampler for physical measurements.

General data relative to the milk plants and their waste systems are given in Table I. The milk intake at all plants is moderately low as is the volume of waste. At Plant D the waste volume is extremely low, apparently because of careful use of water, good housekeeping, and complete separation of whey from other wastes. The waste volumes are based on drawdown pumping data with the exception of Plant C where the record keeping by the operator was very erratic. At that plant it was necessary to assume that the water meter readings represented a close approximation of the waste volume.

The cost of the irrigation equipment varied widely, since existing equipment was used for parts of the systems and construction labor was supplied by the owner in some installations. In general, however, the costs were moderate as compared to conventional types of treatment plants. The cost of four

TABLE I.—General Data for Five Milk Processing Plants and Their Wastewater Handling Systems

Item	Plant Designation				
	A	B	C	D	E
Milk intake (avg lb/day)	20,500	10,600	20,000	13,500	33,500
Waste volume (avg gpd)	4,300	1,135	1,770	380	5,900
Cost of irrigation system (\$)*	837	800	1,550	400	2,300
Acres irrigated:					
Total	0.97	0.213	0.65	0.018	1.15
Each setting	0.194	0.213	0.216	0.006	0.33
Pumping rate (avg gpm)	11	15.2	19.7	6	34
Pumping duration (avg min/day)	391	75	90	63	174
Application rate (avg in./hr)	0.13	0.16	0.20	2.3	0.23

* Excluding land cost.

TABLE II.—Average and Range in Cation and Anion Content of Certain Milk Processing Plant Wastes in mg/l

Plant Designation	Nitrogen		Phosphorus		Potash		Sodium		Calcium		Magnesium		Chlorides	
	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range
A	—	—	17.1	6.5-27	57.8	26-118	166	103-216	76	46-92	49.6	32-60	180	128-278
B	170	93-319	132	33-194	138	31-452	374	282-642	76	43-101	40.6	20-140	264	104-710
C	180	108-298	59.7	24-105	160	54-388	433	98-675	78.6	47-105	34.9	13-60	494	160-943
D	58	19-110	35.2	16-62	46.6	16-147	255	168-329	57.9	32-107	35.7	19-49	162	57-354
E	43	10-111	31	12-77	37	4-62	470	183-796	66	44-94	37	24-60	559	186-1,000

other systems (excluding land) in Northern Wisconsin varied from \$1,200 to \$2,400.

The extent of the irrigated areas showed wide variation from plant to plant. At Plant D there was appreciable runoff to a cover area, hence the 0.018 acre is not truly representative. The application rate at this plant was roughly ten times that at the other plants; therefore, the runoff was not entirely unexpected.

Elemental Composition of the Wastewater

The chemical composition of milk plant wastes is extremely variable (Table II) and was found to vary not only with the time of sampling during a given day but also from day to day. These data emphasize the fact that grab samples have relatively little value for waste composition determinations. The nitrogen, phosphorus, and potassium content of the wastewaters is much higher than those usually found in municipal sewage. It is believed that the major source of the nitrogen is from the milk spilled or lost during processing, since no other source of nitrogen was observed. If this is true, then the differences in the average nitrogen content of the waste from a given plant is a fairly reliable check on the amount of milk lost during processing. From the nitrogen analyses it is evident that there is wide variation between plants in this respect.

The high phosphorus and potassium content probably comes from the cleaning compounds used in the plants.

Many of these compounds are high in phosphorus or potassium or both. Here, again, the variability in the average phosphorus and potassium content of the wastes from the different plants is striking. This may be a reflection of the differences in kind and quantity of the cleaning compounds used. Because the water probably would be the major source of the calcium and magnesium, much less variability was found in the average values of these cations in the wastes from the different plants.

With the exception of sodium, the concentrations of the nitrogen, phosphorus, and other elements found in the wastes present no problem from the standpoint of spray irrigation. In fact, they can contribute markedly to the nutritional requirements of the crop being irrigated, as was evident at two sites (B and D).

The potential dangers of excessive amounts of sodium in an irrigation medium, particularly where fine textured soils are concerned, are well known. Although this problem was recognized, the high sodium content found in the wastes from the plants studied was not expected. The major source of sodium in the wastes is from the salt (NaCl) used in the plant. The wide variation in the sodium content of the wastes between plants would tend to indicate that with reasonable care the sodium content of the wastes could be greatly reduced. It is worthy of note that at one plant when the owner was absent for a few days the sodium content of the waste more than doubled.

The deleterious effects of sodium in the wastewater on soil aggregation or structure are not only dependent on the amount of sodium applied but also on the amount of other cations present. From the many studies carried out on the quality of irrigation water in relation to its use on western soils, the following formula (11) has been used for determining the suitability of the water:

$$\text{Percentage Na} = \frac{\text{Na} \times 100}{\text{Ca} + \text{Mg} + \text{Na} + \text{K}}$$

where cations are in gram equivalents per million. To be suitable for irrigation of western soils, the equivalent percentage of sodium should not exceed 80, nor should the total concentration of cations, in equivalents per million, exceed 25. The percentage of sodium in the wastes included in this study ranged from 63 for Plant B to 44 for Plant E, thus indicating that they would be safe from this standpoint. Wastes from three of the plants, however, had total concentrations of cations which exceed the recommended permissible limit. The average total cation equivalents per million in the waste from Plants B, D, and E were 29.8, 27.0, and 28.3, respectively. Wastes from the other two plants averaged well below the recommended permissible limit with respect to the total cations. It is believed that in the more humid regions a fairly high salt concentration in itself does not constitute a serious problem because of the greater amount of leaching in the soils of these regions.

Soil Analyses

The analyses of soil samples taken the second year of irrigation are presented in Table III. These tests indicate that a substantial increase in all ions has occurred in the soil, particularly in the 0-to-6-in. layer. On the soils that were low in available phosphorus and exchangeable potassium, the grass crop exhibited a marked im-

provement resulting from these nutrients in the wastewater.

Exchangeable calcium and magnesium contents are not presented because even though large additions were being made via the waste, the changes in the soil calcium and magnesium contents were relatively minor. Large amounts of these ions are normally present (on the order of several thousand pounds of calcium and 500 lb of magnesium per acre-half foot). However, the importance of the calcium and magnesium in the waste in counteracting the deleterious effect of sodium on the soil should not be minimized, as explained later. As expected, sodium and chlorides exhibit the greatest increase in the soil. Chlorides and sodium are normally low in soils of the humid region unless recently fertilized or heavily pastured. In the latter case large amounts of NaCl are added to the soil via the animal droppings when they are receiving liberal amounts of salt. This probably accounts for the relatively high sodium content of the unirrigated soil at site B. The relatively high chloride content of the unirrigated soil at site D is believed to be the result of lateral movement, since the chloride ion is one of the few ions that readily moves with the soil water. Several more years of irrigation will be needed to determine whether soil sodium content will reach harmful levels or whether equilibrium will occur before this happens. From the studies on quality of irrigation water in western states it appears that the sodium is not present in the wastes in harmful amounts.

Soil Tests with Sodium

The harmful effects of sodium on the physical condition of the soil are shown in Figure 1. The differential treatments were as follows:

1. Sample at left was leached with 500 ml of distilled water.
2. Middle sample was leached with 500 ml of city water, containing 70

**TABLE III.—Influence of Milk Plant Wastes on Acid Soluble Phosphorus,
Water Soluble Chlorides, and Exchangeable Bases in the Soil**

Soil Depth (in.)	Acid Soluble P (mg/l)		Water Soluble Cl (mg/l)		K (mg/l)		Na (mg/l)	
	Irrig.	Unirrig.	Irrig.	Unirrig.	Irrig.	Unirrig.	Irrig.	Unirrig.
(a) PLANT A								
0-6	42.0	23.3	52.0	8.0	186	164	127	20
6-12	28.1	7.0	25.0	8.0	157	160	67	25
12-18	28.8	10.4	24.0	10.0	165	119	46	24
18*-24	36.6	7.6	28.0	8.0	310*	180	44	34
24*-30	62.0	27.4	20.0	6.0	290*	205	41	33
30*-36	75.0	55.8	16.0	8.0	300*	193	41	36
36*-42	103.0	69.4	16.0	8.0	233*	175	39	33
42*-48	124.0	72.0	8.0	8.0	200*	183	38	37
(b) PLANT B								
0-6	96.7	62.3	83.0	48.0	250	90	213	128
6-12	51.7	51.3	59.0	27.0	134	70	52	93
12-18	57.3	51.0	48.0	20.0	174	95	56	55
18-24	58.8	51.0	44.0	22.0	182	106	53	40
(c) PLANT C								
0-6	72.9	37.4	390	12.0	168	72	447	26
6-12	56.7	37.2	280	11.0	72	51	268	23
12-18	54.1	35.8	295	22.0	53	48	185	23
18-24	39.8	33.9	231	16.0	50	62	104	27
24-30	39.8	44.0	214	17.0	62	62	108	22
30-36	37.9	45.0	181	19.0	54	85	92	27
36-42	64.3	44.3	230	20.0	62	97	118	29
42-48	47.7	44.8	215	21.0	63	92	110	27
(d) PLANT D								
0-6	68.8	46.7	28.0	6.0	347	265	152	22
6-12	61.1	28.4	30.0	24.0	222	118	109	29
12-18	28.9	15.6	42.0	33.0	179	156	118	27
18-24	22.7	13.8	36.0	36.0	178	165	106	58
24-30	19.0	30.7	28.0	40.0	180	192	110	74
(e) PLANT E								
0-6	43.0	15.3	52.0	12.0	111	94	143	30
6-12	10.8	21.2	32.0	8.0	72	58	217	13
12-18	13.0	22.4	72.0	19.0	53	60	178	12
18-24	17.0	23.2	80.0	22.0	64	127	106	19
24-30	20.2	22.0	55.0	28.0	53	95	109	16

* Till or rock encountered in one of the excavations, therefore these values represent only one profile.

mg/l Ca and 53 mg/l Mg, to which 1,000 mg/l Na as NaCl had been added. After the differential treatments had been made, the soil in each funnel was leached with 500 mg/l distilled water containing 500 ml of distilled water except for the

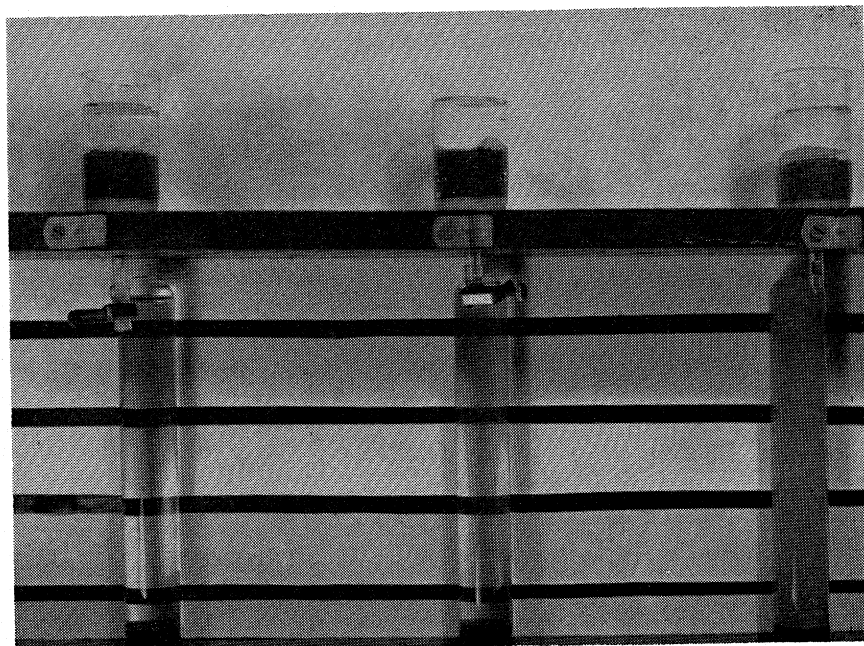


FIGURE 1.—Test apparatus showing soil structure as affected by sodium in the irrigation water when in the presence of calcium and magnesium.

third sample. In this case the soil became virtually impervious after about 250 ml of water had passed through. The soil structural breakdown in this test is evident not only in the appearance of the soil but also in the turbidity of the leachate. The turbidity is the result of dispersed soil particles passing through the cotton filter. The soil in the middle funnel exhibits only slight dispersion, as evidenced by the slight turbidity of the leachate. The beneficial effect of calcium and magnesium in irrigation water containing sodium can be explained as follows.

Soil clays, because of their negative charge, hold a large amount of cations in exchangeable form. When sodium constitutes about 15 per cent of the total exchangeable cations, the soil clays begin to disperse and dispersion increases with an increase in sodium content. When the soil is irrigated with water containing only the sodium cation, replacement of the other cations occurs until a high percentage of the

exchangeable cations is sodium. Depending on the sodium content of the irrigation water, it may be many years before any noticeable deterioration of soil structure occurs. Also if sodium chloride or sulfate is present in the soil solution, it serves as a strong electrolyte and no dispersion occurs until it has been leached out by rains. Once the sulfates or chlorides have been leached, dispersion is very rapid if the soil clays contain a high percentage of sodium. Calcium and/or magnesium are more tightly bonded to clay than is sodium. Hence the presence of relatively small amounts of these cations in the irrigation water will have a marked depressing effect on the adsorption of sodium by the clay. Also, if the calcium and magnesium are present as the chlorides or sulfates, any sodium in the soil water remains in the chloride or sulfate form until leached from the soil. For example, in the laboratory test shown in Figure 1 the soil leached with city water containing 1,000 mg/l

sodium contained less than a third as much exchangeable sodium as the soil irrigated with water containing the same amount of sodium but no other cations (NaCl in distilled water). Soils that receive large additions of sodium, but only small amounts of calcium and magnesium, via the irrigation route, are benefited by applications of calcium sulfate at a rate of two or more tons per acre every few years.

Analytical Control Characteristics

Analytical characteristics of the wastes usually associated with wastewater treatment control, Table IV, also show extreme variations between plants and within each plant depending on the time of sampling. High concentrations of organic matter were indicated by the values found for BOD, COD, and volatile residue. Undoubtedly the main source of this organic material was milk spillage and the dumping of whey into the wastewater. Good house-keeping and efficient operation of a milk plant can markedly reduce the strength of the wastes, as shown by the relatively low BOD and low volume of waste at Plant D. In contrast, the waste from Plant B has 3 times the volume and approximately 4 times the concentration of that from Plant D, or about 12 times as much oxidizable matter from approximately the same milk intake.

The pH and alkalinity values similarly showed wide variations, indicating differences in the freshness of the wastes as they are applied to the soil. The average pH values were rather low for all wastes, but at Plant B the values were consistently low, undoubtedly due to the presence of appreciable lactic acid, indicating that active bacterial decomposition was regularly taking place in the holding tank before the wastes were applied to the soil. Such a condition is conducive to the development of odors at the irrigation site. Odors at Plant B were more common than at the other plants. In general, the low pH values were encountered during the summer when biological activity was more rapid.

For summer operation the use of a smaller holding tank, more complete pumpage from the tank, and more frequent cleaning should reduce the extent of biological decomposition of the waste before being sprayed, thus lessening the possibility of odors. For winter operation, however, a tank large enough to hold a full day's flow of the waste is frequently more desirable in order that manual operation of the irrigation system does not become burdensome.

The suspended solids content of the wastes was relatively high and rather variable. All plants were equipped with screening devices for removing large particles from the waste, but the

TABLE IV.—Analytical Characteristics of Milk Processing Wastes Usually Associated with Wastewater Treatment Control

Item	Plant A		Plant B		Plant C		Plant D		Plant E	
	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range
BOD (mg/l)	1,752	860-4,740	4,790	1,849-9,440	4,310	1,980-9,100	1,280	435-2,220	936	400-1,620
COD (mg/l)	—	—	4,520	1,467-11,500	7,800	3,740-15,320	1,703	552-2,830	1,241	366-1,880
Ammonia (mg/l)	—	—	19	1-68	36	20-76	15	2-40	7	1-31
Organic N (mg/l)	40	31-55	151	92-251	144	88-222	43	17-70	36	9-80
Alkalinity (mg/l)	—	—	359	0-582	81	0-272	505	0-1,088	249	0-389
pH	—	—	5.6	4.0-7.2	4.8	4.2-5.7	6.8	4.6-9.5	6.4	4.1-8.7
Total solids (mg/l)	—	—	5,450	3,296-11,434	6,490	3,540-11,990	2,280	1,208-3,326	2,653	1,000-8,610
Total volatile solids (mg/l)	—	—	3,800	749-9,404	4,740	2,444-9,988	1,350	554-2,346	1,240	365-3,720
Total suspended solids (mg/l)	—	—	1,025	510-1,800	1,040	600-1,940	361	273-502	619	220-1,980
Volatile suspended solids (mg/l)	—	—	998	488-1,540	910	500-1,840	303	200-390	561	220-1,720

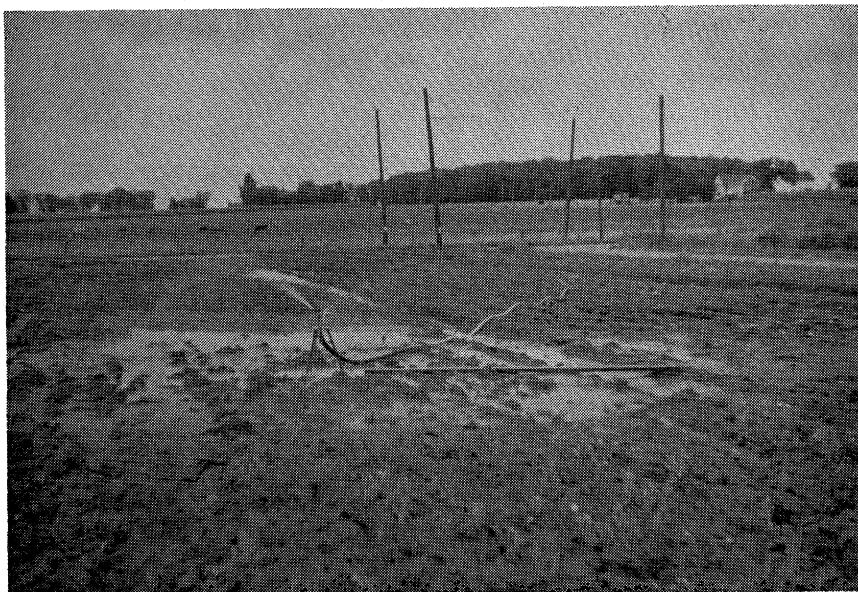


FIGURE 2.—Dairy waste spray irrigation site showing ponding on newly seeded, poorly drained soil.

finer remained in the liquid which was sprayed. This leads to the proposed possibility that excessive amounts of these solids would tend to decrease the permeability of the soil and might lead to the development of odors. Good screening operations are essential to prevent clogging of the spray nozzles, especially during cold weather when a clogged nozzle quickly becomes a frozen nozzle. The wastes having high BOD values also showed high suspended solids content, indicating general inefficiency in the operation of the dairy plant itself. The suspended solids were almost completely volatile, indicating the loss of milk products in the form of cheese curd and various solids formed during decomposition in the waste holding tank.

Irrigation Rates

When estimating land needs for the disposal of wastes by crop irrigation, the dairy plant operator is interested in the average daily amount of waste that can be applied to a given area. Obviously, there are no hard and fast

rules that can be applied by all dairy plants for predicting loading rates, because these rates will vary from site to site with variations of kind of soil and underlying strata, nearness to the water table, and climatic conditions. With the plants under study, variations between fields in safe loading rates were quite striking. At Plant C the soil was sandy in texture and the water table was at a depth of about five feet. There were no dense clay layers in the profile. Consequently, when the irrigation line was left in the same position for over a two-month period during the summer of 1956, no ponding or damage to the crop resulted. In contrast, at Plant B where the field being irrigated was silt loam overlying a fairly tight clay, runoff occurred almost every day shortly after irrigation was begun. However, because the irrigated portion of the field was at the head of a long draw, no ponding, and consequently no damage to the vegetation, resulted. It should be pointed out that because of this situation the area actually used for disposal at site D was much

larger than the specific area covered by the sprinklers (.006 acre).

The objectionable results of over-irrigation are evident in Figure 2. This site is not one that was under measurement, but is one of the sites included in a survey of a larger number of existing irrigation disposal systems. The soil is a silt loam overlying a very slowly permeable clay at a depth of two feet below the surface. Since the topography is level, objectionable ponding resulted. This field had been seeded a short time before the date of this photograph and outside of the irrigated area the vegetation was beginning to cover the soil. However, in the irrigated and ponded areas, the vegetation was completely killed. It is evident that, when soils and topographical conditions such as shown in Figure 2 exist, irrigation or loading rates will be largely governed by transpiration and evaporation (about 0.2 in./day during the growing season in the Wisconsin area).

Although some plants are better adapted than others to a restricted soil-

oxygen supply, no plant will live long when the soil is water-logged with media containing as much organic material as those encountered in this study. On the other hand, the large amounts of easily oxidizable materials which occurred in the wastes constitute no serious problem when the irrigation system is well managed. Thus, it appears desirable to observe the crop under irrigation to make a final evaluation of design application rates. The health of the crop is one good criterion to use in judging whether excessive application rates have been used.

Winter Irrigation

Year-round irrigation was carried on at three of the plants under study. During the winter months this resulted in an ice sheet of about 18 in. around the sprinklers. In all cases the irrigation pipe had been raised off the ground two feet or more. Special precautions for pipe drainage were necessary to avoid damage to the irrigation system. Also, the plant operators

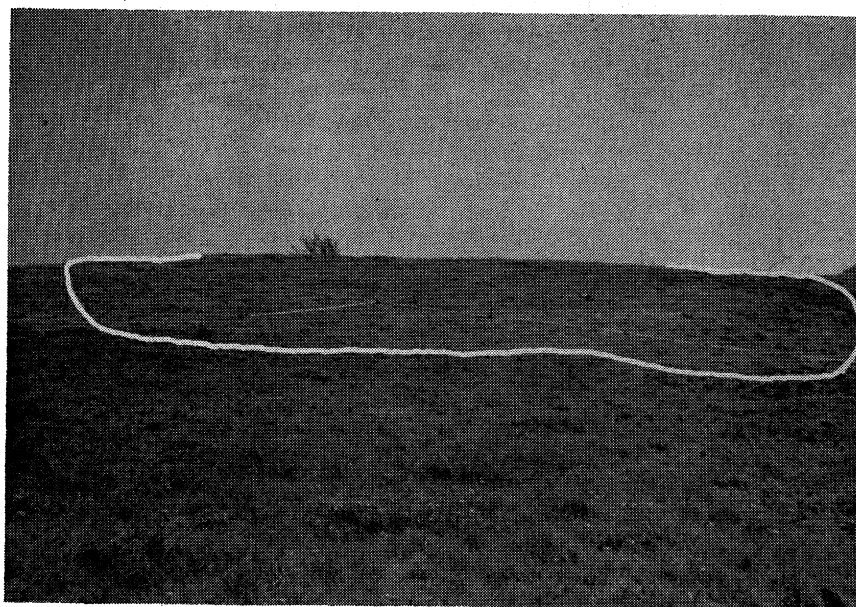


FIGURE 3.—Irrigation field showing crop injury (within the imposed line) as the result of a winter ice sheet.

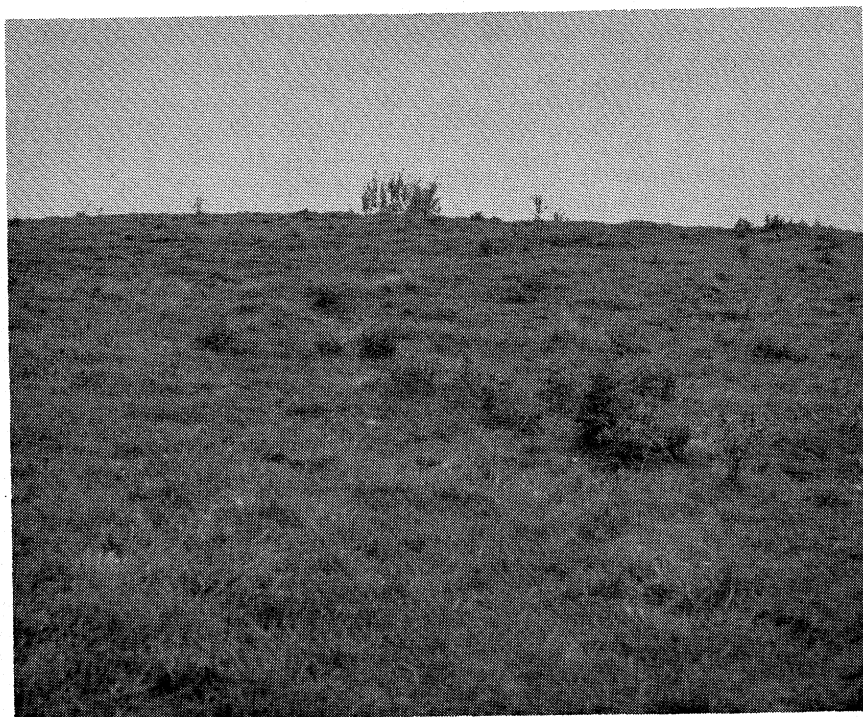


FIGURE 4.—Same field as in Figure 3, showing recovery of grass crop by July following winter irrigation.

found that, because of the inherent dangers to the irrigation system, manual operation during the winter months was almost a necessity. Much more attention, therefore, was required during the winter operation.

In the spring before ground temperatures were above freezing, the thawing ice sheet caused runoff. No objectionable odors resulted because the air temperature remained relatively low during the period of thawing. By the time air temperatures were high the ice sheet had disappeared.

In all cases the original vegetation (mostly quack and blue grass) was very slow in recovering or was killed out completely in the area covered by ice. At site C, a level field, the grasses never did return and it was necessary to reseed the area killed. At site E the crop was very slow to recover (note enclosed area, Figure 3), but by July there was no difference between the area covered by ice and the

uncovered areas (Figure 4). The latter site differed from site C in that it was on a fairly steep slope, and this may be the explanation for the differences encountered. It is likely that, where winter disposal by means of irrigation is being followed, the plant operator may have to plan on re-establishment of the crop the following spring on the winter-irrigated area.

Some operators in northern Wisconsin are using spray irrigation for spring, summer, and fall disposal, and are switching to other methods for winter disposal. At one of these plants the cooling waters are discharged to a roadside ditch and the strong wastes to septic tanks during the winter. At another plant winter disposal is accomplished by ridge and furrow irrigation with good success.

Conclusions

1. Spray irrigation appears to be a practical, economical, and satisfactory

method of disposal of dairy wastes where the irrigated area is properly selected and reasonable care is exercised in the operation of the system.

2. The volumetric loading and the cation loading appear to be the principal design factors when considering spray irrigation. The BOD loading is much less significant than it is in the design of biological treatment systems.

3. Reasonable predictions of loading or irrigation rates of a given site may be made when soil conditions, type of cover crop, depth of water table, etc., are known. However, final design application rates can best be determined by observance of the crop under irrigation.

4. The waste-holding tank, during summer operation, should be small (perhaps 2 to 3 hr maximum detention time), should be emptied completely during each pumping period, and should be flushed frequently to remove accumulations of solids which will otherwise cause objectionable odors.

5. From a mechanical standpoint, winter operation of spray irrigation systems is possible in areas comparable to the latitude of central Wisconsin, but it must be assumed that a complete kill of the cover crop will occur. However, the irrigation operation may be reasonably carried out by having alternate plots available in order that reseedling may be accomplished readily.

6. An evaluation of the effect of runoff from the ice cover during winter and from the spring thawing of the ice cover itself should be made at each site, based on the dilution available by the stream and on other factors peculiar to the site.

7. Hot wastes that are damaging to the cover crop may be successfully irrigated by elevating the spray nozzles, thus allowing the waste to cool as it falls.

8. In some irrigated areas having poor absorption characteristics, the use

of tile systems several feet below the surface have greatly increased the flow of waste through the soil. The effluent from the tile systems has been found to be low in BOD and relatively stable. There are some soils, however, that are difficult to drain. Therefore, a thorough analysis should be made before drainage is undertaken.

9. In cold areas, serious consideration should be given to alternate methods of disposal during the winter period.

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